## 1 | Use Case Title: MineCo Crusher Optimization

## 2 | Use Case Overview *(<=100 words) Provide a brief description of the use case and the system that your autonomous AI will improve.*

• MineCo mines precious metals from ore.​

• The first and roughest stage of ore processing is crushing the ore, in this case with a gyratory crusher

• Operators manually control supervisory settings for the gyratory crusher.

• The particle size and hardness entering the crusher and the crusher itself, particularly the condition of the liner, vary with an unknown random distribution.  This makes it very difficult to control the crusher well.

• The objective of this project is to train a brain(s) to provide supervisory control settings for the underground gyratory crushers at the MineCo South site that maximize the throughput of fragmented ore.

## 3 | Optimization Goal *List and describe the key performance indicators that will define control/optimization of the system (Example: maximize (throughput)*

The goal is to maximize.

The KPI is throughput.

It is measured in tons / hour.

The throughput is the amount of material that passes through the crusher on to high pressure grinding rolls (HPGR) having met the 65mm fineness criteria for particle size.

## 4 | Use Case Value (<=100 words) Explain the value of improving the performance of this system.

A 5% improvement in throughput generates a predicted ROI of $10M / year at the mine site in question.

## 5 | Current Methods Select and explain the current methods used to control or optimize the system

|  |  |  |
| --- | --- | --- |
|  | Method Check all that apply | Description |
|  | Human Operator / Engineer | **Supervisory Control**: The fixed plant team currently gaps the crushers once every 24 hours. This leads to sub-optimal results and is time intensive. |
|  | Expert System |  |
|  | Control Theory (PID, MPC) | **Low-Level Control**: The advance process control system utilizes both PID and MPC control systems. |
|  | Optimization Techniques |  |
|  | Other |  |

## 6 | Limitations of current methods *Select and explain the limitations of current methods*

|  | **Limitation**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Ability to control well across scenarios / conditions | Human operators find it difficult to manage the changing particle size distribution and the changing hardness distribution of the incoming ore. |
|  | Multiple or changing optimization goals |  |
|  | Human Operator /  Engineer Limitations  May include  · Difficulty managing many variables and dimensions  · Difficulty adapting to changing conditions  · Large performance discrepancy between novice and expert operators  · Inconsistency across expert operators | Difficulty adapting to changing conditions: Human operators find it difficult to manage the changing particle size distribution and the changing hardness distribution of the incoming ore.  Large performance discrepancy between novice and expert operators: Expert operators gain expertise over many years. |
|  | Uncertainty in the measurement of the inputs or the process make it difficult to control or optimize. |  |
|  | Time to develop control or optimization system is prohibitive |  |

## 7 | Autonomous AI Components *Select and explain the automation methods your AI will use.*

|  | **Method**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Math (control systems) | We’ll continue using PID and MPC for low-level control of the system. |
|  | Menus (optimization) |  |
|  | Manuals  (expert rules and systems) |  |
|  | Machine learning | We might want to use a ML module with advance perception to predict the hardness of the incoming rocks. |
|  | Deep reinforcement learning | We have identified two strategies, which will be implemented with 2 DRL modules:   * When particle sizes are larger and /or ore is harder, choke the crusher (fill it up to the top) * When incoming particle sizes are smaller and / or ore is softer, regulate the crusher (fill it up to 2/3) |

## 8 | Autonomous AI Superpowers *Select the superpowers that your autonomous AI brain will exhibit and explain how they will lead to an improvement in the process.*

|  | **Superpower**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Makes human-like decisions | The DRL modules that implement the two strategies will autonomously learn human-like decisions |
|  | Perceives, then acts | If we decide to add a Machine Learning algorithm to our brain design for advance perception, the brain will perceive and the chose the best action to take for each scenario |
|  | Learns and adapts | The Deep Reinforcement Learning modules will practice in simulator to learn the strategies, even in unlikely scenarios |
|  | Spots patterns | If we decide to use Machine Learning for advance perception, the brain will spot patterns and will be able to classify/predict the type of rock that is entering the crusher |
|  | Infers from experience | The DRL part of the brain practices in simulator, therefore it infers from that experience. |
|  | Improvises and strategizes | The DRL part of our brain will certainly learn strategy and it will adapt to rare situations because it would have already practice on those scenarios |

## 9 | Control Actions *Select and explain the level of the control actions that the brain will output to control or optimize your system*

|  | **Level**  Check all that apply | **Number of Actions** | **Description** |
| --- | --- | --- | --- |
|  | Supervisory | 3 | The brain will provide supervisory set points. |
|  | Low Level |  | Low-level control will remain with the APC controllers. |

## *Identify the type of control actions that the brain will output to control or optimize your system*

| **Name** | **Data Type** | **Units** | **Control Frequency** | **Operating range [min, max]** | **Description** |
| --- | --- | --- | --- | --- | --- |
| ROM Feeder Speed |  |  | hourly (once per hour) | [0-100] with steps of 5 | The speed of the crusher feeder; this dictates how much ore is coming into the crusher. |
| Crusher Gap Setpoint |  |  | hourly (once per hour) | [10-20] with steps of 1 | The setpoint for the smallest distance (gap) between between the mantle liner and concave liner on the closed side  The crusher gap is currently changed in minimum increments of 10mm. For example, if the gap needs to be changed by 5mm, it will be increased by 15mm and then decreased by 10mm. |
| Throat Level |  |  | hourly (once per hour) | [80-100] with steps of 5 | Vertical distance between the top of the crusher and the crusher gap |

## 10 | Constraints *List and describe what constraints are placed on the control actions by the system or the process Example: Maximum crusher gap changed allowed per hour is 15 mm.*

- Engineering limit on the Mantle Height: 25mm to 275mm. Control actions that result in mantle heights of less than 30mm should not be used for safety.

- Maximum crusher gap change allowed per hour is 15mm.

## 11 | Environment States / Sensors *List and describe what information do we need to pass to the BRAIN about the system and its environment for the BRAIN to learn to control or optimize the system*

| **Name** | **Data Type** | **Source** | **Units** | **Measurement Frequency** | **Operating Range [min, max]** | **Description** |
| --- | --- | --- | --- | --- | --- | --- |
| ROM Bin Level |  |  |  | minute (once per minute) | [50-100] | Percent of capacity that the ROM bin is filled |
| ROM Feeder Speed |  |  |  |  | [50-100] | The speed of the feeder delivering uncrushed rock into the crusher​ |
| COB Bin Level |  |  |  |  | [50-100] | Percent of capacity that the Crushed Ore Bin (COB) bin is filled |
| COB Low/High Microwave Sensors |  |  |  |  | [50-100] | Sensors for determining if the COB is either approaching full or empty. Will trigger stops for feeder conveyor belts when reached.​ |
| COB Feeder Speed |  |  |  |  | [50-100] | The speed of the feeder delivering uncrushed rock out of the COB bin to the main conveyor​ |
| Throughput |  |  |  |  | [50-200] | The amount of ore that passes through the crusher and goes to HPGR having met the 65mm quality criteria. |
| Weight-o-meter |  |  |  |  | [0-200] | The amount of ore that leaves the crushed ore bin |
| Fragmentation |  |  |  |  | [0-100] | Ore size as reported by ore size camera |
| Current Gap Setpoint |  |  |  |  | [10-20] | The setpoint for the smallest distance (gap) between between the mantle liner and concave liner on the closed side |
| Throat Box Sensor |  |  |  |  | [60-100] | Provides an indication of the rock level within the crusher |
| Crusher Power |  |  |  |  | [10-100] | Power delivered to operate the crusher |
| Mantle Height |  |  |  |  | [50-100] | The linear height of the hydraulics controlling the crusher gap width as measured by the mantle linear sensor |
| Crusher liner wear |  |  |  |  | [0-100] |  |
| Demand predictions |  |  |  |  | [0-100] | Amount of ore expected to be mined |
| Surface Expected |  |  |  |  | [0-10] | Amount of ore expected on the surface |

## 12 | Goals *List and describe what Key Performance Indicators (KPI) define the control or optimization of this system*

| **Goal (KPI)** | **Units** | **Description** |
| --- | --- | --- |
| Maximize Throughput | tons/hour | The amount of material that passes through the crusher on to high pressure grinding rolls (HPGR) having met the 65mm fineness criteria for particle size. |
| Maximize Efficiency | tons/hour | Depending on customer demand. The crusher must sometimes run-in efficiency mode. This is a secondary priority to maximizing throughput. |
| Minimize waste | tons/hour | As part of maximizing efficiency, waste material must be reduced. |

## 13 | Scenarios *List and describe what we need to vary in the training to ensure that the brain works well across scenarios*

| **Configuration Variable** | **Range**  **[min, max]** | **Description** |
| --- | --- | --- |
| Particle Size Distribution |  |  |
| Ore Hardness Distribution |  |  |

## 14 | Training Episode Length *Describe the training episode length for your use case. An episode represents the number of control actions that comprise a scenario Example: in an HVAC scenario control actions for an air conditioning unit might be taken 4 times per hour, but multiple hours need to be considered to see a diverse range of building occupancy and the temperature variation during the day. If the training episode is one day, there are 24 x 4 control actions per training episode.*

In the gyratory crusher, control actions are taken every 15 minutes. The training episode is one day. There are 24 x 4 control actions per training episode.

## 15 | Benchmark Episode Length *Sometimes, the benchmark scenario needs to be longer than the training scenario in order to capture the full range of variation of the configuration variables. To extend the example above, benchmarking an HVAC system requires extending the prediction scenario for a trained BRAIN to include seasonality across months. In this case, the benchmark episode length may be 1 year (356 x 24 x 4 control actions).*

The benchmark for the gyratory crusher is one month.

## 16 | Skills / Strategies *Use subject matter expertise to identify the strategies to include in your brain design to control or optimize your system*

| **When the [environment variable list] trend in this direction or interact in this way…** | **This is what we think it means** | **This is what you should do (to manipulate control actions)** |
| --- | --- | --- |
| If incoming particle sizes are larger and / or ore is harder | More compression is required | Choke the crusher |
| If incoming particle sizes are smaller and / or ore is softer | This is a higher throughput opportunity | Regulate the crusher |
| If the crusher is getting too full, especially with smaller particles. | You may bog (clog up) the crusher in which case it will need to be stopped and manually unclogged. | Slow down the feed into the crusher |

## 17 | Other Skills / Concepts *Select and explain all type of skill or concepts in which you will decompose your brain design to control or optimize your system*

|  | **Type of skill or concept**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Controllers (Open loop, FF, MPC, etc.) |  |
|  | Optimization algorithms |  |
|  | Strategy or Function | We are going to use 2 concepts to implement the first two strategies described above |
|  | Selector | We are going to use a selector to select what strategy to each in each scenario |
|  | Advance perception, classification or prediction |  |
|  | Expert Rules / Constraints |  |

Choke Crusher

Feed

Regulate Crusher

Feed

Varying Particle Size and Hardness

Varying Particle Size and Hardness

Input

Output